Resource Quality, Agricultural Productivity, and Food Security in Developing Countries

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Abstract: Raising agricultural productivity improves food security both through increased incomes for farmers and through increased food supplies for consumers. Productivity depends in turn on a variety of factors, including the quantities of fertilizer, water, and other inputs used in agricultural production. Recent advances in data and analysis show how productivity also depends critically on the quality of inputs used, including the quality of natural resources such as land. Within Sub-Saharan Africa, the productivity of agricultural land is found to be 28 percent higher in countries with favorable soils and climate than it is in countries with poor land quality, everything else being equal, and in Asia the difference is 34 percent. Productivity is especially responsive to increases in the use of fertilizer and irrigation in countries with poor land, while productivity in countries with good land is more responsive to improvements in labor quality and transportation infrastructure. Reductions in the incidence of armed conflict are important in both sets of countries.

Keywords: land quality, agricultural productivity, food security.

Resource Quality and Agricultural Productivity

Sustained growth in agricultural productivity is critical to improving food security for two reasons. First, growth in agricultural productivity translates into increased food supplies and lower food prices for consumers. Second, growth in agricultural productivity means higher incomes and thus improved ability to purchase food and other basic necessities, for many food-insecure people who earn their livelihoods through agricultural production.

Agricultural productivity depends in turn on a variety of factors. Recent studies (e.g. Craig, Pardey, and Roseboom, 1997, and Frisvold and Ingram, 1995) indicate that most differences in agricultural productivity, whether across households or countries or over time, can be attributed to differences in the quantity of conventional inputs used in agricultural production, such as land, labor, fertilizer, and machinery. But agricultural productivity also depends critically on the quality of inputs used, including the quality of natural resources such as land. As simple as this statement seems, the influence of resource quality on agricultural productivity has received insufficient attention in the past because appropriate data have been scarce. However, recent advances in data and analytical methods (see box, "Data and Methods") allow improved understanding of the ways in which agricultural productivity and food security are affected by differences in the quality of resources. Distinguishing the relative impacts of input quantity and quality is important in determining appropriate policy measures to improve agricultural productivity and food security.

Soils and Climate

Land—embodying soils, climate, and other characteristics—is one of the most basic resources used in agricultural production. Figure A-1 illustrates global differences in land quality, based on assessments by USDA's Natural Resources Conservation Service of the suitability of soils and climate for agricultural production. Extensive areas of high-quality land are evident in North America and Europe. Land is of lower quality, on average, in Latin America, Asia, and Sub-Saharan Africa, and is poorest of all in North Africa, the Middle East, and Central Asia.

Figure A-2 illustrates global differences in average annual rainfall. Rainfall may be more equitably distributed on a global scale than is high-quality land, but substantial variations remain within regions and countries. Latin America receives abundant rainfall, on average, with the exception of northern Mexico, northeastern Brazil, and the western coast of South America. Western and central Africa receive more rain than northern, eastern, and southern parts of the continent, while southeast Asia and adjoining areas receive more rain than northern and western portions of India and China.

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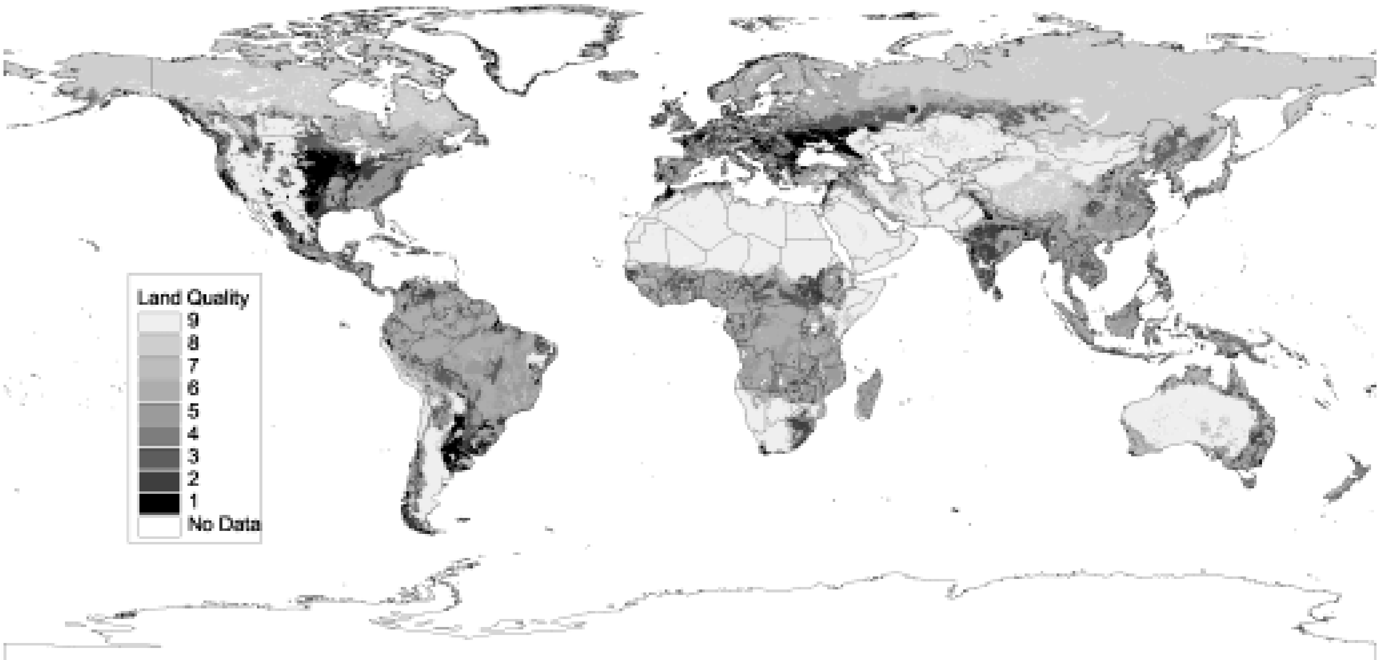
Figure A-1

Global land quality

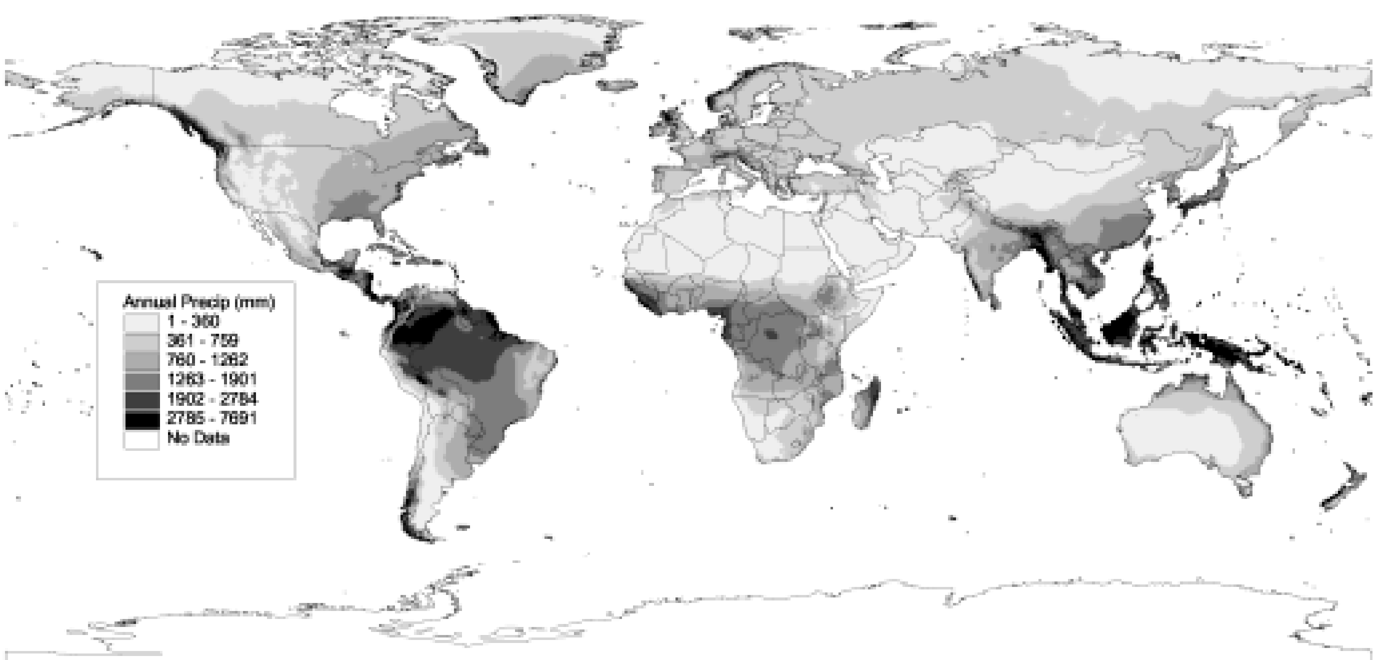


Note: Land quality class 1 represents the land most suitable for agricultural production, i.e. having the fewest inherent soil and climate constraints.

Source: NRCS/USDA.

Figure A-2

Global mean precipitation, 1961-96



Source: Climatic Research Unit, University of East Anglia.

Poor soils and climate do not make agricultural production impossible, but they do mean that costs of production are likely to be higher and/or that yields and net returns are likely to be lower than they would be under more favorable conditions. (In other words, agricultural productivity is likely to be lower.) Figure A-3 illustrates where crop production actually dominates the landscape, based in part on land quality and rainfall patterns, along with other physical and economic characteristics. Large concentrations occur in North America, Europe, India, China, Brazil, and Argentina; cropland is more sparsely distributed in Africa and the Middle East.

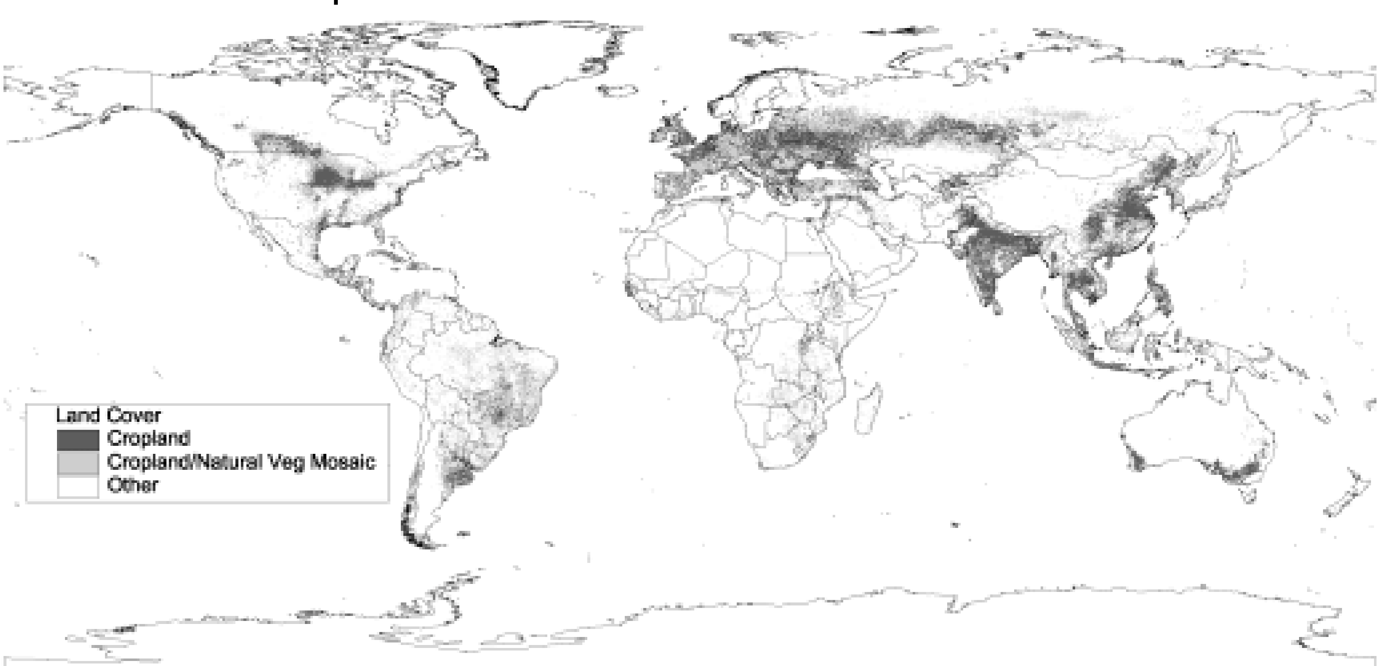
Combining this information on soils, climate, and land cover allows us to compare the quality of cropland by country and region. While the quality of all land is, on average, lowest in the Middle East and North Africa, the quality of cropland is lowest in Sub-Saharan Africa. In 12 of 38 Sub-Saharan African countries studied, less than 1 percent of cropland is classified in the top three land-quality classes, and the median share of cropland that is classified in the top three land-quality classes in Sub-Saharan African countries is about 6 percent (fig.A- 4). This compares with a median of 16 percent in Asia (where 7 of 17 countries studied have more than a quarter of their land in the top three classes), 19 percent in the Middle East and North Africa (where 3 of 8 countries studied have more than a quarter of their land in the top three classes, and 27 percent in Latin America (where 12 of 19 countries studied have more than a quarter of their land in the top three classes). By contrast, the median share of high-quality cropland was 29 percent in the high-income countries, as defined by the World Bank (where 13 of 22 countries studied have more than a quarter of their land in the top three classes) and over 50 percent in Eastern Europe (where all six countries studied have more than a quarter of their cropland in the top three classes).

Not surprisingly, econometric analysis of 110 countries during 1961-97 (see box, "Data and Methods") reveals that after taking into account other factors such as input levels, differences in the quality of cropland soils and climate are significantly related to differences in agricultural productivity. Within Sub-Saharan Africa, the productivity of agricultural land is 28 percent higher, on average, in countries with high land quality than it is in countries with poor land quality. The productivity difference attributable to high land quality is 34 percent in Asia, and 22 percent in the high-income countries. (In Latin America, where most countries lie above the global median in terms of land quality, only the best soils and climate are significantly associated with increased agricultural productivity.)

These findings confirm our expectations and provide for the first time an empirical estimate of the significance that differences in the inherent physical quality of soils and climate have on agricultural productivity. Perhaps more important, however, are the insights they provide into the impact on agricultural productivity of more conventional inputs, such as quantities of land, labor, fertilizer, and machinery.

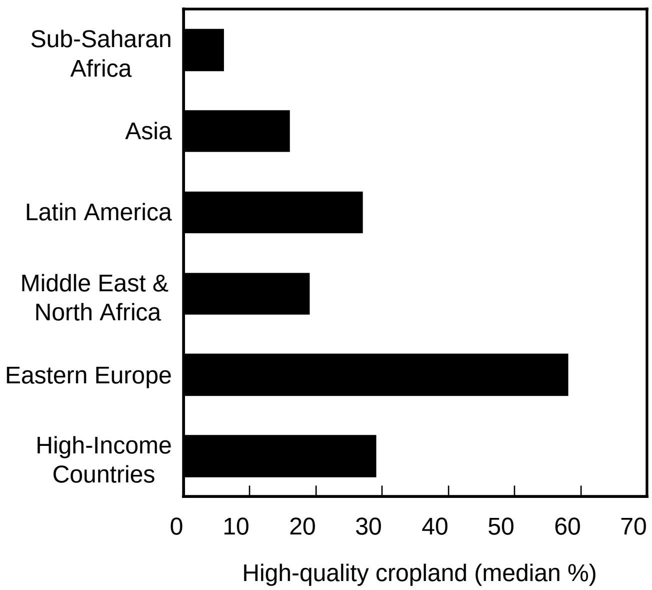
Figure A-3

Global distribution of cropland



Source: USGS/UNL/JRC Global Land Cover Characterization.

Figure A-4
Cropland quality



Conventional Inputs and Other Factors

To capture these impacts, we included in our econometric analysis country-level measures of conventional agricultural inputs like agricultural land, labor, tractors, livestock, and fertilizer. We also included factors such as annual rainfall on cropland, the percentage of each country's agricultural land that is classified as arable land or permanent cropland, the percentage of arable land or permanent cropland land that is not irrigated, life expectancy and illiteracy rates (as measures of labor quality), an indicator of the occurrence of armed conflict (as a measure of institutional stability), and road density and cumulative agricultural research and development expenditures (as measures of infrastructure). (Data on agricultural research and development expenditures were available only for 1961 through 1985, but they revealed a significant and positive association with agricultural productivity during that time.)

Within each region, countries were classified according to the share of their cropland that is highly suitable for agricultural production (see box, "Data and Methods"). Countries where this share exceeds the median value for their region were identified as having good soils and climate; those with less than the median were identified as having poor soils and climate. Each group of countries was then analyzed separately to compare the impacts of individual factors on agricultural productivity by region and land-quality class.

In Sub-Saharan African countries with good soils and climate, agricultural land productivity rises significantly with increases in quantities of labor, livestock, tractors, fertilizer, and annual rainfall. Productivity also improves with irrigation, labor quality (in the form of longer life expectancy and higher literacy rates), and transportation infrastucture and falls significantly with the occurrence of armed conflict. In Sub-Saharan African countries with poor soils and climate, productivity responds even more strongly to fertilizer application, irrigation, and political instability, but it is not sensitive to improvements in tractors, labor quality, or infrastructure. Overall, the results suggest a land quality-related hierarchy of constraints limiting agricultural productivity in Sub-Saharan Africa. In countries poorly endowed with soils and climate, basic inputs such as fertilizer, water (in the form of irrigation), and institutional stability are more important than they are in countries that are relatively well endowed. The evidence suggests that only when these constraints have been overcome do factors such as labor quality, road density, and mechanization become significantly associated with improvements in agricultural productivity—as they are in countries with better soils and climate.

Similar patterns characterize other developing regions. In Latin America, increases in labor, fertilizer, and irrigation are associated with increased productivity of agricultural land in countries with poor soils and adverse climate but not in countries with good soils and beneficial climate. Improvements in literacy and transportation infrastructure are associated with increased productivity in countries with good soils and climate but not in those that are poorly endowed. In Asia, additional land, labor, and roads increase agricultural productivity in counties with good soils and climate but not in those that are poorly endowed, where productivity is relatively more sensitive to increased irrigation. (Specifically, productivity is positively related to an increase in irrigated area, but some authors (e.g. Rosegrant 1997) have noted that degradation of irrigated areas through waterlogging and salinization is also a significant and growing problem.) In the Middle East and North Africa, agricultural productivity is sensitive to levels of labor, tractors, and literacy in well-endowed countries but not in countries with poor soils and climate, where (as in Asia) productivity is relatively more sensitive to increased irrigation.

Analysis of inherent land quality thus improves our understanding of the impacts on agricultural productivity of factors over which policy makers exercise at least some influence. The policy implications of these findings will be discussed further below. Analysis of differences in land quality across countries and regions also provides an initial indication of the potential impact on agricultural productivity of changes in land quality (i.e. land degradation) over time. Data on land degradation rates and impacts remain even more scarce than data on land quality, but most studies to date have found that global average productivity losses due to processes such as soil erosion, nutrient depletion, and salinization are small (on the order of 0.1 - 0.2 percent per year) in relation to historic gains in productivity (on the order of 2 percent per year) due to improvements in technology and input use (den Biggelaar et al. forthcoming, Crosson 1997; Byerlee, Heisey, and Pingali 1999; Pinstrup-Andersen, Pandya-Lorch, and Rosegrant 1999). Nevertheless, in some areas with poor or fragile soils and inappropriate agricultural management practices, productivity losses could be significantly higher

Data and Methods

We examined the impact of resource quality on the productivity of agricultural land, using for the first time recent global data on soils, climate, and land cover. We began with data developed by Eswaran et al. (1997), who combined FAO's Digital Soil Map of the World and associated soil characteristics (e.g. slope, depth, and salinity) with spatially referenced longrun average temperature and precipitation data to establish nine land quality classes in terms of their suitability for agricultural production (fig. 1). Wiebe et al. (2000) then overlaid these land quality classes with political boundaries and global land-cover data generated from satellite imagery with a resolution of 1 kilometer United States Geological Survey/University of Nebraska-Lincoln/Joint Research Centre of the European Commission (USGS/UNL/JRC, 1999). They focused on cropland identified according to the International Geosphere-Biosphere Programme land cover classification scheme (fig. 2). The result is a dummy variable based on the share of each country's cropland that is found in the three best quality classes. Countries where this share exceeds the median value for their region are identified as having good soils and climate; those with less than the median are identified as having poor soils and climate.

This static measure, based on cross-country differences in inherent soil and climate characteristics, supplements existing time-variant quality indicators such as the percentage of agricultural land that is cropped (or irrigated) and long-term average or annual rainfall. To better capture this last effect, we also developed a high-resolution measure of annual rainfall by aggregating and overlaying monthly precipitation data on a 0.5-degree grid (fig. 3; Climatic Research Unit 1998) with national boundaries and cropland as described above. The result is a country-specific, time-variant measure of rainfall on cropland.

The dependent variable in our analysis is the productivity of agricultural land, measured as the value of total agricultural production (the sum of price-weighted quantities of all agricultural commodities, expressed in international dollars, after deductions for feed and seed) per hectare of agricultural land (the sum of arable land, permanent cropland, and permanent pasture). Other variables include country-level indicators of agricultural labor, tractors, livestock, and fertilizer, as well as measures of the quality of labor, the institutional environment, and infrastructure. The data are combined in an econometric analysis of 110 countries during 1961-97. Additional detail is provided in Wiebe et al. (2000).

(Scherr 1999, Lal 1998). That such conditions are found in parts of Sub-Saharan Africa, where productivity levels are already low and the need for growth is correspondingly high is cause for concern.

Implications for Food Security and Policy

As noted earlier, agricultural productivity is important for food security both through its impact on food supplies and prices and through its impact on the incomes and purchasing power of those whose livelihoods depend on agricultural production. Through its effect on agricultural productivity, land quality is thus related directly to both food availability and food access. Land quality is, on average, lower in low-income, food-deficit countries than it is in high-income countries, and agricultural productivity is more sensitive to differences in land quality. These relationships have important implications for policymakers concerned with improving food security, both through protection and/or improvement of land quality itself and through recognition of the distinct roles played by more conventional agricultural inputs in areas that differ in land quality.

In Sub-Saharan African countries with relatively poor soils and adverse climate, for example, the policy-sensitive variable most strongly associated with agricultural productivity is irrigation, followed by armed conflict and fertilizer use. Among the policy measures most important for increased agricultural productivity in those countries are thus investments in the efficient delivery and use of water and fertilizer, combined with efforts to improve institutional stability through the cessation of armed conflict. In Sub-Saharan African countries with good soils and climate, these factors remain important, but agricultural productivity becomes relatively more sensitive to improvements in labor quality and infrastructure. Policymakers in those countries may need to focus additional resources on investment in education, health, extension services, and transportation.

Similar conclusions apply in other regions as well. In Latin American countries with relatively poor soils and climate, agricultural productivity and thus food security are likely to respond most strongly to policy measures to improve efficiency in the use of fertilizer and water and to reduce the occurrence of armed conflict. In Latin American countries with better land, productivity responds much more strongly to improvements in labor quality, infrastructure, and mechanization, suggesting the need for investments in education, transportation, and capital. Improvements in irrigation, education, and conflict reduction are important in Asian countries with poor land, while improved transportation remains important in Asian countries with good land. Increased application of fertilizer is not associated with improved agricultural productivity in Asia, regardless of land quality, reflecting the relatively high levels of use already observed there. In the Middle East and North Africa, not surprisingly, improvements in irrigation offer the greatest potential gains in agricultural productivity.

Results and implications are generally consistent with the expectation that the greatest improvements in agricultural productivity will be realized by relaxing the constraints that bind most tightly and those constraints will vary from region to region according to differences in resource endowments and other factors. Neither is it surprising that the quality of soils and climate should play a key role in defining these differences. Yet only recently, with improvements in spatial data and methods, has characterizing these differences with increased precision at the multi-country scale become possible. Analysis to date supports the conclusion that policy-makers in low-income, food-deficit countries face a hierarchy of priorities that depends critically on the quality of soils and climate but that is broadly consistent across regions. Continued research will be needed to further refine our understanding of the relationships of resource quality, agricultural productivity, and food security.

References

Byerlee, Derek, Paul Heisey, and Prabhu Pingali (1999). "Realizing Yield Gains for Food Staples in Developing Countries in the Early 21st Century: Prospects and Challenges." Presented to the Study Week on Food Needs of the Developing World in the Early 21st Century, the Vatican, January 27-30.

Climatic Research Unit (1998). Climate Impacts LINK Project (U.K. Department of the Environment Contract EPG 1/1/16), Climatic Research Unit, University of East Anglia.

Craig, Barbara, Philip G. Pardey, and Johannes Roseboom (1997). "International Productivity Patterns: Accounting for Input Quality, Infrastructure, and Research." *American Journal of Agricultural Economics*, Vol. 79, pp. 1064-76.

Crosson, Pierre (1997). "Will Erosion Threaten Agricultural Productivity?" *Environment*, Vol. 39, No. 8, pp. 4-31 (October).

den Biggelaar, Christoffel, Rattan Lal, Keith Wiebe, and Vince Breneman (2001). "Soil Erosion Impacts on Crop Yields in North America." *Advances in Agronomy*, Vol. 72, No. 1, pp. 1-52, 2001.

Eswaran, Hari, Russell Almarez, Evert van den Berg, and Paul Reich (1997). "An Assessment of the Soil Resources of Africa in Relation to Productivity." *Geoderma*, Vol. 77, pp. 1-18.

Frisvold, George, and Kevin Ingram (1995). "Sources of Agricultural Productivity Growth and Stagnation in Sub-Saharan Africa." *Agricultural Economics* Vol. 13, pp. 51-61.

Lal, Rattan (1998). "Soil Erosion Impact on Agronomic Productivity and Environmental Quality." *Critical Reviews in Plant Sciences* Vol. 17, No. 4, pp. 319-464.

Pinstrup-Andersen, Per, Rajul Pandya-Lorch, and Mark W. Rosegrant (1999). *World Food Prospects: Critical Issues for the Twenty-First Century*. Food Policy Report, International Food Policy Research Institute, Washington, DC.

Rosegrant, Mark W. (1997). *Water Resources in the Twenty-First Century: Challenges and Implications for Action*. Food, Agriculture, and the Environment Discussion Paper No. 20. International Food Policy Research Institute, Washington, DC. March.

Scherr, Sara J. (1999). *Soil Degradation: A Threat to Developing-Country Food Security by 2020?* Food, Agriculture, and the Environment Discussion Paper No. 27. International Food Policy Research Institute, Washington, DC. February.

United States Geological Survey/University of Nebraska-Lincoln/Joint Research Centre of the European Commission. (1999). "Global Land Cover Characterization. U.S. Geological Survey, University of Nebraska-Lincoln, and European Commission's Joint Research Center <http://edcwww.cr.usgs/landdaac/glcc/glcc.html>.

Wiebe, Keith, Meredith Soule, Clare Narrod, and Vince Breneman (2000). "Resource Quality and Agricultural Productivity: A Multi-Country Comparison." Selected Paper presented at the Annual Meeting of the American Agricultural Economics Association, Tampa, FL, July 31, 2000 <http://agecon.lib.umn.edu/aaea00/sp00wi01.pdf>.